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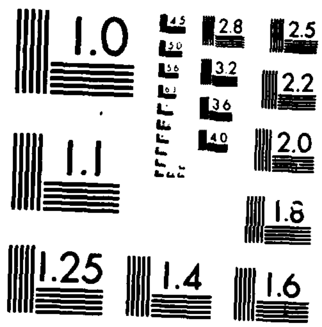

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DEMONSTRATION OF A STATISTICAL METHOD FOR ISOLATING TIMESHARING COMPONENTS

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AN OBJECTIVE STATISTICAL METHOD FOR ISOLATING TIMESHARING COMPONENTS OF PERFORMANCE IS DESCRIBED AND DEMONSTRATED. DURING THE FIRST STAGE OF THIS METHOD, PARTIAL CORRELATION ANALYSIS IS USED TO REMOVE THE VARIANCE ATTRIBUTABLE TO THE SINGLE-TASK MEASURES. DURING THE SECOND STAGE, THE RESULTING DUAL-TASK PARTIAL CORRELATIONS ARE SUBJECTED TO A FORM OF "FACTOR ANALYSIS." DATA FROM BOTH SVERKO (1977) AND WICKENS, MOUNTFORD, AND SCHREINER (1981) WERE REANALYZED AND THE RESULTS COMPARED WITH THEIR EARLIER ANALYSES, AS WELL AS WITH THE REANALYSIS OF THE LATTER STUDY BY ACKERMAN, SCHNEIDER AND WICKENS (1984). THE CHARACTERIZATION OF TIMESHARING FACTORS AND THE QUESTION OF A GENERAL TIMESHARING FACTOR ARE ALSO DISCUSSED. USING THE PROPOSED METHOD, SUBSTANTIAL EVIDENCE FOR MULTIPLE TIMESHARING COMPONENTS WAS FOUND.

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INTRODUCTION

During the last decade, there have been several attempts to isolate a general timesharing ability that affects only multiple-task performance (Hawkins, Rodriquez, and Reicher, 1979; Jennings and Chiles, 1977; Sverko, 1977; Wickens, Mountford, and Schreiner, 1981). All of these attempts have met with little success.

Ackerman, Schneider, and Wickens (1984) have recently described a number of methodological problems that may have obscured the existence of a general timesharing ability in these studies. These authors discuss solutions to these problems and present a method for identifying such an ability using Procrustian Rotation. Although we generally agree with the solutions to the methodological problems presented by Ackerman et al.(e.g., Damos, Bittner, Kennedy, and Harbeson, 1981), we feel that their proposed analytical method suffers from two major problems. First, their method is based upon a relatively sophisticated tool which, in addition to a number of limitations, relies heavily upon subjective judgements by its practitioners (Harman, 1976, pp. 336-360). Second, Ackerman et al. have applied this tool to mixtures of single-task and dual-task measures, thereby clouding the identification of unique dual-task abilities. These problems have led us to consider alternate approaches for isolating one or more timesharing components of performance. (Throughout this paper we have used the statistical term "components" rather than "skills" or "abilities" to avoid the controversy surrounding these latter terms).

This paper describes a method for isolating timesharing components that is less subjective than the Procrustian Method. The described method, in

addition, is intended to be easily applied and uses computer routines that are readily available. Although several packages would have served as well, all calculations were performed using the BMDP Statistical Software (Dixon, 1981). This statistical package was selected for illustrative purposes as it is widely available in industry, government, and academia. To demonstrate this approach, data from both Sverko (1977) and Wickens, Mountford, and Schreiner (1981) were reanalyzed. The results reported in this paper for the Wickens, Mountford, and Schreiner data are also compared to results obtained by Ackerman et al. (1984). Although the reports by Sverko (1977), Wickens et al. (1981), and Ackerman et al. (1984) showed little, if any, evidence for multiple timesharing components, substantial evidence is reported in this paper.

METHODS AND RESULTS

Statistical Approach

The statistical analysis is conducted in two stages. During the first stage, partial correlation analysis is used to remove the variance attributable to the single-task measures from the dual-task measures. Specifically, all of the single-task measures are partialled out of all of the dual-task measures using the BMDP6R Program (Dixon, 1981, pp. 509-518). (This program also provides for easy examination of individual dual-task scores with the single-task variance removed). Although it may seem more appropriate to partial out only the single-task variance of the tasks that compose each dual-task combination, there are two reasons for taking this approach. First, in most cases, all of the single-task measures are correlated with all of the dual-task measures (both of the examples given in this report show this pattern of correlation). If dual-task performance is determined both by

one or more unique timesharing components, as well as by several single-task components, it is necessary to account for the contribution from all of the single tasks to identify the unique timesharing components. Second, by partialing out all variance that is associated with single-task scores, the maximum amount of variance that may be attributed to timesharing components becomes apparent. Thus, the first stage of analysis is aimed at calculation of the dual-task intercorrelations free of all single-task variation.

During the second stage, the resulting dual-task partial correlations are subjected to a form of "factor analysis." The BMDP4M principal factor analysis with a minimum (1.1) eigenvalue cutoff and varimax rotation was used (Fame, Jennrich, and Sampson, 1981). This option was selected primarily because it provides for an easy and straightforward analysis.

In summary, the general statistical approach involves factor (structural) analysis of the dual-task measures from which all the single-task variance has been removed.

Two Applications

For illustrative purposes, the statistical approach described above will be applied to two data sets collected by Wickens et al. (1981) and Sverko (1977). In both examples, scores are included from each task of a dual-task combination. Thus, X(Y) refers to the score of Task X performed with Task Y and Y(X) refers to the score of Task Y when performed with Task X.

Wickens, Mountford, and Schreiner (1981). In this experiment, subjects performed a critical tracking task (T), a number classificaton task (C), an auditory running memory task (A), and a line judgement task (L). The subject performed each task alone and then all dual combinations, with the exception

of the auditory running memory task which was not performed with itself. Table 1 shows the intercorrelations of the four single and 15 dual-task measures from the Wickens et al. experiment (these correlations are given in Ackerman, Schneider, and Wickens, 1982). Table 2 shows the partial intercorrelations between the 15 dual-task measures with all the single-task variance removed. The reader should note that the partialed intercorrelation matrix shows significant positive correlations between the C, L, and A measures, although significant and substantial ($p<.00001$) portions of the variance of each measure had been extracted. The specific percentages removed were: T(T), 46%; T(C), 72%; T(L), 53%; T(A), 84%; C(T), 68%; C(C), 73%; C(L), 59%; C(A), 70%; L(T), 51%; L(C), 53%; L(L), 40%; L(A), 63%; A(T), 53%; A(C), 45%; and, A(L), 34%. Of interest in the partialed matrix, the T measures show no substantial correlation with the other dual-task measures although highly correlated among themselves. This pattern of partial correlations suggests one or more factors accounting for the relation between the C, L, and A dual measures with another factor accounting for the T dual measures.

TABLES 1 AND 2 ABOUT HERE

Principal Factor Analysis of the partial correlation matrix resulted in a four-factor solution that explained 72.4% of the total variation. Table 3 shows the rotated factor solution. Examining this table, it may be seen that Factor 1 has substantial ($\geq .5$) loadings of .831 on A(C), .799 on L(A), .741 on C(A), .712 on A(L), and .630 on A(T). This pattern of loadings involving "A" suggests labeling this a "dual auditory running memory task" factor. Similarly, Factor 2 has substantial loadings of .831 on T(C), .820 on T(A),

.812 on T(L), and .680 on T(T), which suggests labeling this a "dual tracking task" factor. Factors 3 and 4 are not easily characterized; they appear to be mixes of the L and C tasks in dual combinations. Factor 3 in particular has substantial loadings of .821 on L(C), .785 on L(L), .727 on C(C), .552 on C(L), and .537 on A(T). We have tentatively identified this as a "dual L/C task" factor. In contrast, Factor 4 has its largest loadings of .835 on C(T) and .771 on L(T). This factor could be labelled "dual L/C (T)" or perhaps "dual discrete task with tracking." Altogether, Table 3 reflects a number of dual components that are defined by the tasks or their characteristics that are independent of single-task measures.

TABLE 3 ABOUT HERE

Sverko (1977). In this experiment, the subjects performed four tasks and their six combinations: Pursuit rotor (PR), digit processing (DP), mental arithmetic (MA), and auditory discrimination (AD). Table 4 follows the format of Table 1 and is based on the raw data. It shows the correlations between the four single-task measures as well as the 12 measures obtained from the six dual-task combinations. Table 5 shows the partial correlations of the dual measures when all the single-task variance has been removed. As in the earlier analysis, significant ($p<.0001$) proportions of the dual-task measures were partialed out. Specifically, these were: PR(DP), 47%; PR(MA), 56%; PR(AD), 72%; DP(PR), 26%; DP(MA), 29%; DP(AD), 66%; MA(PR) 82%; MA(DP), 64%; MA(AD), 74%; AD(PR), 60%; AD(DP), 50%; and, AD(MA), 48%. Contrasted with the earlier analysis (Table 2), the structure of the resulting matrix (Table 5)

shows some added complexity. The correlation of -.42 between DP(PR) and PR(DP), for example, indicates a performance trade-off not seen in the earlier analysis. However, there are prominent clusters of modest positive correlations between scores of the same task performed in different combinations (e.g., PR(DP), PR(MA), and PR(AD)). This pattern of partial correlations suggests multiple factors with each factor associated with the timesharing component of a specific task.

TABLES 4 AND 5 ABOUT HERE

Principal Factor Analysis resulted in a four-factor solution that accounted for 59.8% of the variance in the partial correlation matrix. Table 6 shows the rotated factor solution. Examining this table, it may be noted that the factors are each identified with specific tasks in dual combinations: Factor 1 with AD; Factor 2 with PR; Factor 3 with MA; and Factor 4 with DP. Factor 1, for example, has substantial loadings of .824 on AD(DP), .773 on AD(MA) and .710 on AD(PR). Thus, Table 6 presents dual-task capabilities that are defined by specific tasks in dual combinations.

TABLE 6 ABOUT HERE

DISCUSSION

The major purpose of this report was to demonstrate an objective technique for identifying one or more timesharing abilities. For purposes of this demonstration, dual-task data from Wickens et al. (1981) and Sverko (1977) were reanalyzed using the proposed technique. In the following

sections, the results of these reanalyses will be contrasted with earlier analyses and implications for a general timesharing factor considered.

Contrasts with Previous Analyses

The statistical approach described in this report has two features that distinguish it from earlier approaches. First, the demonstrated method is based on "factor analysis" of dual-task partial correlations from which all single-task variance has been removed. These dual-task relations are not obscured by the presence of single-task components, which according to Ackerman et al. (1984) have contaminated earlier analyses of the same data (i.e., Wickens et al., 1981; Sverko, 1977). The second feature of the demonstrated approach, which differs from that of Ackerman et al. (1984), is that it does not require human intervention. The demonstrated technique involves successive applications of statistical options drawn from the BMDP Statistical Software (Dixon, 1981). In contrast, the Procrustes Method, advocated by Ackerman et al., requires the user to specify the target structure (cf, Harmon, 1976, pp. 336-360). Potential problems with such specification are numerous, and include: *A posteriori* specifications of structure as well as the possibility, noted by Hurley and Cattell (1962), for making almost any data fit almost any hypothesis. The present method is characterized by its objective analysis of dual-task relations after removal of single-task components.

The above distinctions must be considered when comparing our results with those obtained previously. For example, the present four-factor solution and the four-factor solution of Sverko (1977) initially appear to be similar. Sverko found four rotated factors identified by loadings on each task per-

formed in combination with other tasks but also with equally substantial loadings on the tasks performed alone. For example, his Factor III (which is analogous to the first factor found in this report) had loadings of .89 for AD(DP), .87 for AD(PR), and .85 for AD(MA), but also .92 for AD. Sverko (1977, p. 14), therefore, could not clearly ascribe his results to timesharing factors. In contrast, the present factor solution contains four dual factors which are uncorrelated with the single-tasks measures.

Comparison of the Ackerman et al. (1984) and our analyses of the Wickens et al. (1981) data also requires attention to differences between methods. Ackerman et al. report a four-factor solution. The first factor is identified by single- and dual-task measures of T, the second factor is identified by single- and dual-task measures of both C and L, and the third factor is identified by single- and dual-task measures of A. Because both single- and dual-task measures have substantial loadings on these factors, none was identified as a timesharing factor by Ackerman et al. However, the fourth factor was identified by Ackerman et al. as a timesharing factor. However, both single- and dual-task measures have moderate loadings on this factor, making its identification as a timesharing factor questionable.

The present solution for the Wickens et al. data also yields four factors. However, one factor is clearly identified with Task A, another with Task T, and the remaining two with both Tasks C and L. Since all of the single-task variance was extracted from the data before the PFA was performed, these four factors can clearly be identified as task-specific timesharing factors. The differences between the present results and those of Ackerman et al. are not surprising, given the differences in analytic approaches.

Although initially appearing similar, the results in this report differ substantially from those previously obtained. The primary difference lies in the form of the dual-task relations that result when single-task variation is removed.

Characterization of Timesharing Factors

Our solution of the Sverko (1977) data resulted in four factors, each of which was identified with one of the experimental tasks. Similarly, the first and second factors from our solution of the Wickens et al. (1981) data were clearly identified with the A and T tasks, respectively, while the third and fourth factors were identified with the C and L tasks. However, there is no *a priori* basis for timesharing factors being identified with specific experimental tasks. Indeed, the factors obtained in our analyses may be the result of methodological shortcomings in the original experiments noted earlier by Ackerman et al. (1984). It is suspected that future timesharing analyses will reveal factors that are identified with characteristics of the task combinations, such as "discrete task with tracking," rather than with the specific tasks themselves.

The Question of a General Timesharing Factor

The major question of much of the previous dual-tasks research has concerned the existence of a single general timesharing ability (e.g., Wickens et al., 1981; Sverko, 1977). Our rotated solutions for earlier data show little direct evidence for such an ability or factor (cf, Table 3 and 6). Some indirect evidence, however, was noted during the factor analyses. For example, the first unrotated factor resulting from separate analyses of Tables 2 and 5 accounted for 32.7% and 20.7% of the respective Wickens et al. and Sverko

data. However, as is the case for all such indirect evidence, alternative explanations may be posited. Moreover, the presence of substantial numbers of dual factors in Tables 3 and 6 provide evidence against the concept of a single general timesharing factor or ability. Interestingly, Wickens (1984) has recently argued for multiple timesharing capabilities, based on his review of previous research. Thus, this report, as well as previous research, support the concept of multiple timesharing factors.

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TABLE 1. RAW DATA INTERCORRELATIONS FOR WICKENS, ET AL. (1981)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
T	1	1.00																		
T(T)	2	.65	1.00																	
T(C)	3	.84	.64	1.00																
T(L)	4	.71	.66	.85	1.00															
T(A)	5	.91	.71	.92	.86	1.00														
C	6	.21	.14	.12	.15	.24	1.00													
C(T)	7	.26	.31	.12	.02	.24	.78	1.00												
C(C)	8	.20	.26	.12	.13	.27	.85	.77	1.00											
C(L)	9	.31	.28	.12	.11	.30	.72	.71	.76	1.00										
C(A)	10	.19	.24	.11	.15	.20	.79	.70	.80	.68	1.00									
L	11	-.09	.08	-.20	-.11	-.07	.64	.60	.59	.57	.62	1.00								
L(T)	12	.23	.20	.02	-.09	.14	.56	.77	.61	.78	.64	.64	1.00							
L(C)	13	.30	.28	.21	.24	.36	.67	.64	.83	.70	.68	.56	.61	1.00						
L(L)	14	.23	.37	.19	.26	.34	.54	.59	.72	.78	.60	.54	.65	.78	1.00					
L(A)	15	.05	.23	-.05	.10	.09	.59	.52	.65	.60	.78	.78	.70	.68	.61	1.00				
A	16	.37	.21	.28	.12	.32	.42	.52	.43	.29	.52	.19	.29	.31	.23	.20	1.00			
A(T)	17	.32	.25	.14	.14	.27	.48	.57	.64	.50	.60	.28	.43	.58	.49	.46	.70	1.00		
A(C)	18	.28	.24	.15	.12	.25	.39	.52	.54	.42	.61	.21	.41	.43	.35	.43	.66	.83	1.00	
A(L)	19	.30	.15	.11	.09	.23	.40	.57	.49	.50	.55	.23	.52	.49	.44	.43	.54	.81	.88	1.00

TABLE 2. DUAL-TASK CORRELATIONS WITH SINGLE-TASK VARIANCES PARTIALED OUT FOR WICKENS ET AL. (1981)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T(T) 1	1.00														
T(C) 2	.30	1.00													
T(L) 3	.40	.68	1.00												
T(A) 4	.39	.72	.75	1.00											
C(T) 5	.27	-.12	-.32	-.09	1.00										
C(C) 6	.30	.03	.02	.25	.29	1.00									
C(L) 7	.07	-.25	-.24	-.05	.32	.40	1.00								
C(A) 8	.24	.06	.18	.03	.04	.36	.23	1.00							
L(T) 9	-.06	-.25	-.47	-.28	.61	.27	.61	.31	1.00						
L(C) 10	.08	.07	.08	.25	.16	.67	.32	.29	.25	1.00					
L(L) 11	.28	.15	.20	.35	.25	.59	.61	.30	.38	.62	1.00				
L(A) 12	.22	.02	.20	.13	-.04	.36	.18	.70	.37	.41	.29	1.00			
A(T) 13	.10	-.26	.01	-.04	.19	.51	.33	.27	.21	.48	.40	.46	1.00		
A(C) 14	.14	-.13	.03	.01	.23	.41	.29	.47	.29	.29	.23	.50	.67	1.00	
A(L) 15	-.06	-.27	-.11	-.12	.35	.27	.37	.33	.44	.33	.33	.41	.69	.82	1.00

TABLE 3. ROTATED FACTOR LOADINGS FOR DUAL-TASKS WITH SINGLE-TASK VARIANCES PARTIALED OUT FOR WICKENS ET AL. (1981)

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
T(T) 1	.180	.680	-.007	.355
T(C) 2	-.130	.831	.015	-.138
T(L) 3	.145	.812	.050	-.406
T(A) 4	-.061	.820	.312	-.186
C(T) 5	.045	-.037	.135	.835
C(C) 6	.275	.155	.727	.205
C(L) 7	.128	-.171	.552	.523
C(A) 8	.741	.234	.035	.176
L(T) 9	.270	-.268	.210	.771
L(C) 10	.227	.080	.821	-.002
L(L) 11	.130	.265	.785	.293
L(A) 12	.799	.185	.151	.037
A(T) 13	.630	-.206	.537	-.049
A(C) 14	.831	-.088	.222	.089
A(L) 15	.712	-.289	.307	.166

TABLE 4. RAW DATA CORRELATIONS FROM SVERKO (1977)

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
PR	1	1.00															
DP	2	.42	1.00														
MA	3	.30	.33	1.00													
AD	4	.35	.42	.36	1.00												
PR(DP)	5	.68	.38	.26	.33	1.00											
PR(MA)	6	.67	.29	.48	.42	.59	1.00										
PR(AD)	7	.84	.42	.32	.40	.71	.72	1.00									
DP(PR)	8	.37	.47	.19	.18	.02	.19	.26	1.00								
DP(MA)	9	.34	.45	.36	.40	.33	.33	.40	.34	1.00							
DP(AD)	10	.42	.79	.33	.49	.34	.33	.43	.57	.56	1.00						
MA(PR)	11	.39	.32	.90	.35	.33	.53	.39	.18	.36	.35	1.00					
MA(DP)	12	.25	.26	.80	.28	.28	.42	.26	.14	.24	.30	.84	1.00				
MA(AD)	13	.33	.35	.85	.33	.29	.48	.34	.24	.42	.42	.83	.80	1.00			
AD(PR)	14	.40	.44	.43	.74	.34	.43	.44	.27	.50	.53	.44	.35	.44	1.00		
AD(DP)	15	.37	.49	.36	.66	.27	.41	.37	.26	.40	.64	.36	.31	.36	.72	1.00	
AD(MA)	16	.36	.40	.47	.63	.36	.47	.41	.19	.53	.51	.44	.39	.53	.71	.72	1.00

TABLE 5. DUAL-TASK CORRELATIONS WITH SINGLE-TASK VARIANCES PARTIALED OUT FOR SVERKO (1977)

		1	2	3	4	5	6	7	8	9	10	11	12
PR(DP)	1	1.00											
PR(MA)	2	.24	1.00										
PR(AD)	3	.32	.35	1.00									
DP(PR)	4	-.42	-.10	-.15	1.00								
DP(MA)	5	.08	.04	.14	.15	1.00							
DP(AD)	6	-.05	.02	.04	.37	.31	1.00						
MA(PR)	7	.07	.09	.04	-.06	.04	.10	1.00					
MA(DP)	8	.15	.09	.00	-.03	-.11	.12	.47	1.00				
MA(AD)	9	.06	.09	.02	.09	.19	.28	.27	.39	1.00			
AD(PR)	10	-.01	.01	.07	.09	.24	.16	.09	.02	.15	1.00		
AD(DP)	11	-.10	.10	-.02	.04	.07	.37	.03	.06	.05	.40	1.00	
AD(MA)	12	.10	.14	.09	-.03	.29	.22	-.02	.03	.29	.40	.47	1.00

TABLE 6. ROTATED FACTOR LOADINGS FOR DUAL-TASKS WITH SINGLE-TASK VARIANCES PARTIALED OUT FOR SVERKO (1977)

		FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
PR(DP)	1	-.004	.719	.130	-.241
PR(MA)	2	.069	.613	.091	.032
PR(AD)	3	-.023	.760	-.063	.129
DP(PR)	4	-.085	-.414	-.023	.728
DP(MA)	5	.189	.311	-.092	.642
DP(AD)	6	.277	-.025	.209	.690
MA(PR)	7	-.010	.049	.764	-.020
MA(DP)	8	.008	.019	.854	-.087
MA(AD)	9	.153	.107	.631	.334
AD(PR)	10	.710	.011	.035	.127
AD(DP)	11	.824	-.109	.033	.038
AD(MA)	12	.773	.198	.036	.136

END
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